

THE EFFECT OF PHYSICAL TRAINING UNDER NORMAL AND INCREASED
PARTIAL OXYGEN PRESSURE ON THE STABILITY OF WHITE MICE
TO TRANSVERSE GRAVITATIONAL ACCELERATION AND HYPOXIA

P. V. Vasil'yev and N. N. Uglova

In experiments on white rats it was shown that with optimal physical training programs a distinct increase was observed on the stability of the animals to overheating, cooling, irradiation with X-rays, and to certain infections and poisons [6, 7, 9, 16-19].

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Muscular training of white mice by swimming over a period of 25-60 days increased their resistance to alcohol, oxygen deficiency, high and low temperature, and also to positive acceleration [16-18]. Of course, the evaluation criterion in the latter case was the time for recovery by the mice of the capability to move in a straight line, and it is only natural that such a test does not reflect the overall resistance of the organism to gravitational acceleration. It does make it possible, however, to obtain interesting data on the characteristics of the functional state of the vestibular apparatus.

Combined application of physical training and of dibazole has proved to be more effective than separate application of each.

Analysis of the physiological dislocations that set in when a muscular load is applied [3, 5, 13, 15, 21, 22] and comparison of them with the pathogenesis of disorders occurring during gravitational acceleration have made it feasible to undertake this investigation.

The task of the present paper was the study of the effect of physical training and its combination with hypoxia on the overall stability of animals to the action of transverse gravitational acceleration and gradually developing oxygen starvation (deficiency).

Procedure

The experiments were carried out on 380 semi-mature male white mice weighing 18-25 g. Each test (trained) group had an equivalent control (untrained) group of mice exposed to the same conditions.

The muscular training was accomplished by presenting two types of physical load: primarily static and dynamic. The static load was applied by means of vertical perches, aluminum tubes of 10-mm diameter, the entire length of which was wound with vinyl chloride tape. All the tubes were mounted on a single frame. To reduce sliding by the mice, rubber rings were placed around the tubes at intervals of 3-5 cm. For the purpose of restricting the mobility of the animals and

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by preventing them from jumping off the perches, the latter were partially submerged in low-temperature water. In different experiments the degree of muscular loading was not the same, which was achieved by varying the time spent on the perches and by varying the weight suspended from the base of the tail by means of leucoplaster.

The dynamic load was achieved by having the mice swim in a bath-tub with a water temperature of about 28°.

Under high-mountain conditions (altitude 2100 m) the training was carried out only on the perches; at the same time a group of mice left in Moscow as the control group was trained by the same procedure.

After completing the training period, the animals were subjected to the effect of gravitational acceleration (45 g's, twice for ten minutes at 10-min intervals) on a centrifuge; the arm radius of the machine was 4.7 m. The rate of g-loading was 1 g/sec.

At the same time as the basic investigations to determine the stability of mice to the effect of gravitational acceleration were being conducted, small groups of animals were also being experimented with to study the effect of muscular training on stability to gradually increasing hypoxia. This was done by placing 3-5 experimental mice and the same number of control mice into hermetically sealed desiccators having a volume of 7595 ml. The moisture and CO₂ were absorbed by silica gel and soda lime. The lifetime in the closed space was recorded.

Results and Discussion

As is well known, training effectiveness is achieved by finding optimal training schedules for the problem. At the same time a very essential factor is the form of muscular loading, its magnitude and frequency of application.

N. V. Zimkin [6] indicates that only physiologically justified optical muscular stresses favor the development of progressive changes which facilitate an increase in the stability of the organism to the unfavorable effects of the environment.

On the basis of this fact we tried first of all to determine the optimal training conditions.

The first series of tests was applied to 85 mice. The training lasted 30 days. All the mice were separated into 3 equal-weight groups.

The first group was trained on perches with a 10-g weight attached to the tail. / 250 Training was carried out every other day. The duration of the first session was 3 minutes; each succeeding session was increased by 1 min. The maximum time of physical training at the end of the experiment was 15 min.

The second group was trained daily with the same load. Each day the length of the session was increased by 1 min. Thus, toward the end of the experiment it equaled 30 min.

And finally the third group served as control.

Before and after training the mice were weighed. The results of these observations are presented in Table 1.

TABLE 1. Variation in Weight (in g) of the Trained and Control Mice Over 30 Days

No. of Group	Before Training		After Training		Weight gain in % over the original weight
	No. of animals	Weight	No. of animals	Weight	
1	29	24.6	29	26.9	9.4
2	29	24.7	26	26.7	8.0
3	27	24.1	27	26.7	10.8

From the table it is evident that all the groups had approximately the same gain in weight. The observed differences in weight gain were statistically insignificant. This permits us to assume that the training was not excessive.

On the second day after completion of training the mice were rotated on the centrifuge to determine stability to gravitational acceleration. The experimental results are presented in Table 2.

TABLE 2. Endurance of the Test and Control Mice to the Effect of 45-g Loads

No. of the group	No. of animals	Outcome		Level of survival (%)	Degree of reliability with respect to the control list
		Perished	Survived		
1	29	17	12	24.8	25
2	26	12	14	24.4	22
3	27	20	7	26.9	38

By analyzing the data it can be seen that daily training was more effective. In fact, the survival rate of the second group was 53%, which is 27% greater than that of the control group. The differences in survival rates are considerable.

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Less significant results insofar as survivability is concerned was obtained with the first group, which was trained one day. The difference between this rate and that of the control group totaled 15%.

Thus, even the first series of tests demonstrated that the stability of the organism to g-loading can be appreciably increased by physical training.

The second test series was carried out with 75 mice. In this series, both static and dynamic loads were applied. The mice were divided into three groups.

The first group of animals was subjected to daily training in the form of swimming. Swimming began with 10-minute exposure, and was then increased in each session by 1 min. Swimming lasted 30 minutes in the last seven days.

The second group was trained daily on perches with a 10-g weight.

The third group served as control.

Variation in the weight of the animals during the training period is shown in Table 3.

TABLE 3. Variation in Weight (in g) of Mice During the Experiment With Physical Training

No. of group	Before adaptation		After adaptation		Gain in weight (in %) over the original
	No. of animals	Average weight	No. of animals	Average weight	
1	25	19.9	25	24.8	25
2	25	20	24	24.4	22
3	25	19.5	24	26.9	38

By comparing the data given in Table 3 it can be seen that the mice of the test groups gained less weight than the control mice. The level of physical loading of these animals was approximately the same.

After completing the training period, the mice was subjected to the effect of 45-g's. The results of centrifuging are given in Table 4.

TABLE 4. Survival Rate of Test and Control Mice Subjected to a Load of 45-g's.

No. of group	No. of mice	Outcome		Survival rate (%)	Degree of reliability
		Perished	Survived		
1	20	8	12	60	1.8
2	22	6	16	72	2.8
3	21	14	7	33	-

Analysis of the data confirmed the results of the preceding series. As a matter of fact, the most clearly positive effect on the resistance of the animals showed up after moderate uniform static loading: the survival rate in the second group was 39% higher than in the control group. The differences are statistically reliable. A somewhat lesser, but completely satisfactory effect was also obtained

in experiments with training by daily swimming. The stability to gravitational acceleration in this group was 27% higher than in the control group. /252

Thus, the overall resistance of the white mice to high gravitational acceleration can be substantially enhanced by rational static as well as dynamic training.

It was of great interest to find possibilities for increasing the stability of animals to gravitational acceleration by combined application of physical training and acclimatization to conditions of moderate hypoxia.

For this purpose, we laid on a third series of experiments with 150 mice under high-mountain conditions.

The male mice were divided into 5 equal-weight groups:

- 1) control groups (in Moscow);
- 2) physical training (in Moscow);
- 3) acclimatized group at an altitude of 2100 m (Terskol);
- 4) acclimatized for 2 weeks at an altitude of 2100 m and 2 weeks at an altitude of 3800 m (Ledovaya base);
- 5) physically trained group at an altitude of 2100 m (Terskol).

The original weight of the mice before beginning the experiment fluctuated between 15 and 18 g.

The mice were acclimatized to high-mountain conditions in the area of Mt. Elbrus.

The training of the animals took place every other day. In the first two weeks the weight of the load was 20 g, which corresponded to approximately 100% of the body weight. The training period of 10 min in the first session was increased by 1 min in each succeeding session.

In view of the fact that the mice located at Terskol did not succeed in holding up the load after the 10th day, the weight was decreased to 10 g. This change in procedure was done simultaneously in Terskol and Moscow. Training and acclimatization to high-altitude factors was completed four days before the first rotation on the centrifuge.

Deserving of primary attention is the fact that the weight of the animals did not change equally. The control mice also exhibited the greatest gain in weight; the greatest lag in weight was found in the animals of the fifth group, which were subjected to loading under high-altitude conditions. /253

The test of stability to gravitational acceleration was conducted on the fourth day after returning to Moscow. The results of these experiments are presented in Table 5.

From the given data it is evident that in all the test groups, without exception, the survival rate was higher than in the control group; in the third group, which was located at an altitude of 2100 m above sea level, it was 5.2% higher

TABLE 5. Survival Rate of White Mice Subjected to 45-g Loading Four Days After Acclimatization

No. of group	Experimental conditions	No. of mice	Survival	Survival rate	t
1	Control	28	11	39.2 ± 9.2	
2	Physical training in Moscow	25	14	56.0 ± 9.6	1.3
3	2100 m	27	12	44.4 ± 9.6	0.37
4	2100 + 3800 m	30	19	63.4 ± 9.1	1.9
5	2100 + physical training	29	20	69.0 ± 8.6	2.4

than in the control group, whereas in the fourth group it was 24.4 and in the fifth group 29.8% higher.

Although in statistical processing the difference is significant only in the fifth group, the overall regularity of the increase in survival rate permits us to consider the results as evidence of the positive effect of acclimatization and physical training.

At the same time, active acclimatization, which consisted of a combination of the effects of physical stress and hypoxia, proved to be more effective than passive acclimatization (exposure to high altitude).

The mechanism of the favorable effect of physical training under normal as well as increased partial oxygen pressure is complex; as a matter of fact, in the case of overall physical strain, the reaction takes in almost all the systems of the body, directing efforts to satisfy the increased demand of the body with respect to bioenergy. This is accompanied by an increase in pulmonary ventilation, cardiac activity, erythrocytosis, increased myoglobin, increased glutathione content, higher activity of carbonic anhydrase of the blood, and by other changes [2, 10, 12]. Physical training also promotes the development of the anaerobic component of energy processes in the muscles [4].

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All of this activity is oriented toward overcoming by the organism of the deeper and more prolonged hypoxia that arises in the case of specific levels of physical strain as well as acceleration.

In our experiments on 70 white mice to determine stability to gradually increasing oxygen deficiency it was clearly established that the lifetime of the experimental animals was substantially greater than that of the control animals.

The results of these experiments are given in Table 6.

These data agree with the observations of A.F. Aleksandrov, P.I. Yegorov, A.N. Krestovnikov, et al. [1, 10].

TABLE 6. Lifetime of Trained and Untrained Mice in the Case of Gradually Increasing Hypoxia

Test Series	Experimental conditions	M $\pm$ m (min)	t
I.	Control group	99 $\pm$ 14.0	-
	Trained in swimming for 30 days	162 $\pm$ 10.4	3.15
	Trained on perches with a 10-g weight	140 $\pm$ 17.4	1.69
II.	Control group	107 $\pm$ 0.65	-
	Trained on perches in Moscow	144 $\pm$ 8.2	4.5
	Acclimatization at 2100 m	114 $\pm$ 3.5	1.96
	Acclimatization and training on perches at 2100 m	151 $\pm$ 7.5	5.84

Thus, our investigations have demonstrated that under optimal programs of static as well as dynamic physical training the stability of test mice to the effect of g-loading increases appreciably. Particularly favorable is the combined application of physical loading and moderate levels of hypoxia.

The results of these experiments and comparison of them with clinical physiological reactions to the effect of hypoxia and weightlessness (decrease in mass of circulating blood, plasma loss, reduction of the number of erythrocytes, deterioration in the blood supply of a number of organs and tissues, reduction of muscular tonus and of the overall resistance of the organism to gravitational loads, disruption of metabolism, etc.) permit us to suggest that the method of physical training under periodically created moderate hypoxia may be an effective means for maintaining high stability in the organism of astronauts in the case of prolonged flights.

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